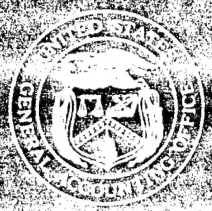
GAO

July 1992

MILITARY AIRCRAFT

C-17 Wing Flap Requires Additional Testing



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United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

B-247741

July 8, 1992

The Honorable Donald B. Rice
The Secretary of the Air Force

Dear Mr. Secretary,

The C-17 military transport aircraft is being developed for the Air Force by the McDonnell Douglas Corporation, Douglas Aircraft Company. It is being designed to carry the full range of military cargo directly into small, austere airfields, a capability that distinguishes the C-17 from other airlift aircraft, such as the C-5, C-141, and C-130. Direct delivery is key to achieving the full potential benefits of the C-17.

Direct delivery capability is provided by a set of interrelated flight characteristics and design criteria incorporated in the C-17 that enables it to approach runways at much lower speeds and steeper descents than conventional aircraft. It can thus land in very short distances with very heavy cargo loads. One of these flight characteristics is powered lift, which involves a unique use of flaps. A flap is a movable attachment to the trailing edge of the aircraft's wing that increases the lift of the aircraft. Powered lift is the result of extending the flaps into the engine exhaust to deflect the exhaust stream. This deflection converts the engine thrust into lift, which permits reduced approach speeds for landing and changes the normal techniques required for aircraft flight path and airspeed control. Standard flaps do not interact with the engine exhaust stream.

Because flap performance is vital to the C-17, we reviewed the results of temperature and acoustic testing to determine whether Douglas Aircraft Company had demonstrated that the flap would achieve the required 30,000-hour life expectancy.

Results in Brief

Testing by Douglas Aircraft and the results of an Air Force review have raised serious concerns about whether the current flap design can meet the contract performance requirement of 30,000 flight hours. Douglas Aircraft tests have shown that an earlier flap design had a life expectancy of only 400 flight hours. Although Douglas Aircraft has since strengthened the flap, it has not retested to demonstrate that the current flap will meet the contract requirement. Actual inflight data collection is being accomplished as part of the flight test program on the test aircraft. The Air Force review team concluded that flap testing needs to be improved and that the C-17 flap should be redesigned because any significant degradation in flap life

expectancy will decrease reliability, require flap replacement, result in aircraft downtime, and increase maintenance costs.

We believe that the Air Force should establish test plans to determine whether the C-17 flap meets the 30,000-hour service life expectancy required before the program goes into full-rate production. That decision is scheduled to be made in March 1995.

Temperature and Acoustic Test Results Show Problems

The C-17's flap is susceptible to heat damage from the engine exhaust stream and to acoustic vibration from engine noise. Heat can ripple or buckle the flap skin and weaken the flap structure. Acoustic vibration can stress the metal and cause cracking, structural damage, or weakening. In tests to determine how hot the flap can get from the engine exhaust, articles tested have shown temperatures that are significantly greater than the temperature used to design the flap. Further, the C-17 flap has failed acoustic tests. A strengthened version of the flap, currently planned for production aircraft, has not been tested.

According to the Air Force review team, because the test articles have not been representative, none of the tests conducted prior to the first flight of the developmental aircraft in September 1991 fully replicated any of the flap designs released for fabrication. Different configurations and metal thicknesses have a direct effect on test results.

Temperature Tests Results

The first temperature test for the flap design was conducted by Douglas Aircraft in July 1986. This test, termed the "boiler-plate test," involved hanging a 6-foot-by-6-foot flat steel plate, simulating a flap, behind a running commercial jet engine. The exhaust from the engine was projected onto the steel plate. The test indicated the flaps would be heated to a maximum temperature of approximately 150 degrees Fahrenheit. The flap for the C-17 was designed using the temperature data obtained from the boiler plate test. However, according to the Air Force review team, a flat plate cannot accurately simulate the curved surface of an actual flap, since different surfaces would show different stress and heat patterns.

Douglas Aircraft performed another temperature test in February 1991. The results from this test showed that the flap would be subjected to maximum temperatures in the 300 degree Fahrenheit range, which is twice the temperature for which the flap was designed. These higher temperatures were attributed to a different test article configuration and a

channeling effect of other portions of the wing on the engine exhaust plume. The test article consisted of major portions of a flap, but according to Air Force officials was still not a representative test article.

Acoustic Tests Results

Acoustic vibration tests were conducted by Douglas Aircraft on a flap test article during June 1990. The article tested consisted of a 5-foot-long box section (an actual flap is about 25 feet long) and included the metallic trailing edge structure, but did not duplicate the entire flap. The test article exhibited internal cracking after 5 minutes of acoustic exposure, indicating a need to strengthen the flap.

Acoustic testing was resumed in September 1990 after the test article was strengthened based on the June 1990 acoustic test. After 1 hour of exposure to the acoustic vibrations, the reworked flap test article showed cracks. The test was discontinued after the article had been exposed to the equivalent of about 1,500 flight hours, or 5 percent of its life expectancy. Inspections revealed cracks in numerous locations. Based on this test, Douglas concluded that the life expectancy of the flap would be 400 hours. Temperature effects, which could also affect the flap life, were not considered in this estimate. This data served as the basis for the redesign of the flap.

Air Force Review Team Recommendations Were Not Implemented

The Director of Engineering for the Air Force's C-17 System Program Office requested that an Air Force team assess the life expectancy of the C-17 flap and determine if Douglas Aircraft's plan to achieve the contractual life requirement was sufficient. The team was made up of representatives from the Air Force Materiel Command, Aeronautical Systems Division.[1] The team conducted its review of the flap in early February 1991 and reported its findings and conclusions to the C-17 System Program Office. Its findings and conclusions were also provided to the Defense Plant Representative Office and Douglas Aircraft.

The review team concluded that the initial structural design of the flap was unacceptable because the flap could not withstand the sound and temperature environment expected in service for the required life of the aircraft. The review team questioned the durability of the flap and concluded that the flap program could and should be improved by:

[1]Previously the Air Force Systems Command, Aeronautical Systems Division.

- immediately starting a development test program, using representative test articles, to obtain design data to support the redesign analysis, and
- testing the final design of the flap through a combined heat and acoustic environment test to prove that the flap will achieve the 30,000-hour life expectancy requirement.

The team concluded that the problems with the flap appeared to have developed because neither the Air Force nor Douglas Aircraft recognized the importance of the flap to the success of the C-17 and its development did not receive sufficient management emphasis and resources.

Douglas Aircraft disputed the findings of the review team and claimed that data gathered during Douglas Aircraft's temperature test in February 1991, which was completed after the review, showed that the flap would operate in a less stressful environment than prior tests had indicated. Douglas believed that the more recent test data would have changed the review team's conclusions and recommendations. We showed the February test data to three of the four review team members. They commented that the additional data would not have changed their recommendations and conclusions.

The Air Force and Douglas Aircraft have begun to acquire actual acoustic and temperature environment data from the flight test program using the developmental aircraft. This will result in assessments of aircraft performance but will not yield flap life-expectancy estimates. To result in life expectancy estimates, the acquired data would have to be used in an environment test, which would take into account the combined effect of sound and heat on the flap. Douglas Aircraft has said that additional testing is unnecessary. Instead, Douglas plans to rely on analysis and extrapolation from the actual data—the same methodology that was used as the basis for the initial design of the flap.

Recommendation

We recommend that the Secretary of the Air Force direct the Program Executive Officer to establish test plans to determine whether the C-17 flap meets the required 30,000-hour life expectancy before the C-17 goes into full-rate production.

Agency Comments and Our Evaluation

DOD concurred with our findings on the results of the temperature and acoustic tests. However, DOD stated that actual ground and flight test data collected to date during flight tests indicate that the temperatures experienced on the flap are a complex function of the flap setting, engine power setting, aircraft airspeed and altitude, and exposure time.

We have examined flight test data that was not available at the time we completed our work on the draft report. Acoustic data collected during both ground and flight testing of the developmental aircraft suggest that the strengthened flap will be exposed to a lower level of acoustic stress in actual service than was earlier believed. However, the Air Force has not been able to obtain adequate acoustic data on the flap trailing edge because heat from the engines destroyed the test monitors.

We have also found that the temperature on the extended flap during flight tests has reached more than 400 degrees Fahrenheit, which is substantially higher than anticipated. As a result, Douglas is adding titanium and additional composite materials to the inboard flaps.

DOD stated that the temperature limits on the original flap design are exceeded only at conditions involving full flap deflection, maximum engine thrust setting, and airspeeds less than 100 knots when sustained for more than 1 minute. However, flight test data we obtained shows that temperatures are exceeded when the flaps are in full deflection, maximum engine thrust setting, and when sustained for only 20 to 25 seconds.

DOD concurred with our finding that the Air Force Review Team recommendations were not implemented. However, DOD stated that it is the responsibility of the C-17 program office to implement a solution with a high probability of success, in a time frame consistent with program requirements, that is affordable in terms of program resources and within the context of all the other programmatic constraints. The findings of the review team were just one source of information that the program office could use in its decision process.

In our opinion, given the independent nature of the review team and its composition (expert knowledge and wide experience), the program office has not given sufficient weight in its decision process to the team's findings.

DOD partially concurred with our recommendation. However, it stated that the recommendation was moot because planned durability and flight testing made further testing unnecessary.

We do not agree that further testing is unnecessary. The C-17 test program includes durability testing. However, the test will be done on a version of the flap that will not be used on a production aircraft. There is no plan to test the wing flaps for life expectancy using environmental data that is representative of the experience expected with heat and acoustic stress simultaneously.

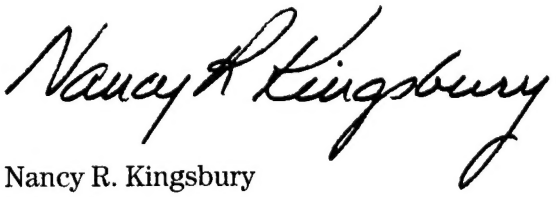
Scope and Methodology

To determine whether Douglas Aircraft Company had adequately established that the C-17 flap would meet the required life expectancy, we reviewed the results of tests of the flaps conducted by the company, reviewed the report of an Air Force review team that examined the probable life expectancy of the C-17 flap. We also discussed the issues with representatives of Douglas, the Air Force C-17 program office, and three of the four members of the review team.

Our review was conducted between February 1991 and April 1992 in accordance with generally accepted government auditing standards.

We are sending copies of this report to the Secretary of Defense, the Director of the Office of Management and Budget, interested congressional committees and subcommittees, and other interested parties. We will make copies available to others on request. If you have any questions please call me on (202) 275-4268. Major contributors to this report are listed in appendix II.

Sincerely yours,



Nancy R. Kingsbury
Director
Air Force Issues

Comments From the Department of Defense

OFFICE OF THE UNDER SECRETARY OF DEFENSE
WASHINGTON, DC 20301

ACQUISITION

24 APR 1992

Ms. Nancy R. Kingsbury
Director, Air Force Issues
National Security and International Affairs Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Ms. Kingsbury:

This is the Department of Defense (DoD) response to General Accounting Office (GAO) draft report, "MILITARY AIRLIFT: C-17 Flap Requires Additional Testing," dated March 25, 1992 (GAO Code 392597), OSD Case 8895-B. The DoD partially concurs with the GAO findings and the recommendation.

Since the GAO completed its onsite work, significant C-17 flap test data and analysis have become available. The C-17 test program also includes plans to determine the flap life expectancy to two lifetimes (60,000 hours), making the GAO recommendation to establish a flap test plan unnecessary.

The detailed DoD comments are provided in the enclosure. Thank you for the opportunity to comment on the report.

Charles E. Adolph
Director
Test and Evaluation

Enclosure

**GAO DRAFT REPORT - DATED MARCH 25, 1992
(GAO CODE 392597) OSD CASE 8895-B
"MILITARY AIRLIFT: C-17 FLAP REQUIRES ADDITIONAL TESTING"**

DEPARTMENT OF DEFENSE COMMENTS

FINDINGS

FINDING A: Status of the C-17 Aircraft Program. The GAO reported that the C-17 military transport aircraft is being designed to carry the full range of military cargo directly into small, austere airfields--a capability known as direct delivery that distinguishes the C-17 from other airlift aircraft. The GAO also reported that direct delivery is provided by a set of interrelated technologies and design criteria. The GAO noted those criteria enable the C-17 to land within very short distances with very heavy cargo loads, and involves a unique use of the flaps, known as powered lift. The GAO indicated the flap is a movable attachment to an aircraft wing that increases the lift of the aircraft. The GAO explained that powered lift consists of extending the flaps into the engine exhaust to deflect the exhaust stream, and then the exhaust stream deflection converts the engine thrust into lift--which reduces the approach speeds for landing and changes the normal techniques required for aircraft flight path and airspeed control. (p. 1/GAO Draft Report)

DOD POSITION: Concur.

FINDING B: Temperature and Acoustic Test Results Show Problems. The GAO learned that the C-17 flap is susceptible to heat damage from the engine exhaust stream and to acoustic vibration from engine noise. The GAO reported that heat can ripple or buckle the flap skin and weaken the internal flap structure, and that acoustic vibration can stress the metal and cause cracking, structural damage, or weakening. The GAO observed that, in tests to determine how hot the flap can get from the engine exhaust, articles tested have shown temperatures that are significantly greater than the temperature used to design the flap. The GAO further found that the C-17 flap has failed the acoustic tests--and that a strengthened version of the flap, currently planned for the production aircraft, has not been tested.

The GAO reported that the first temperature test, conducted in July 1986, indicated the flaps would be heated to a maximum temperature of approximately 150 degrees fahrenheit. The GAO observed, however, that a subsequent test performed in February 1991 indicated the flap would be subjected to temperatures in the 300 degree fahrenheit range--which is twice the temperature for which the flap was designed. The GAO reported that the higher temperatures were attributed to a different test article configuration and a channeling effect of other portions of the

wing on the engine exhaust plume. The GAO noted that, according to the Air Force, the test article used consisted of major portions of a flap, but was still not a representative test article.

The GAO also found that, during the acoustic vibration tests conducted in June 1990, the test article exhibited internal cracking after 5 minutes of acoustic exposure. The GAO also observed that, when testing was resumed with a strengthened test article in September 1990, after 1 hour of exposure to the acoustic vibrations the reworked test article showed cracks and testing was discontinued after the article had been exposed to about 1,500 flight hours or 5 percent of its life expectancy. The GAO noted that, based on the cited test, Douglas Aircraft concluded that the life expectancy of the flap would be 400 hours--and it did not consider the temperature effects on the flap in the estimate. (pp. 2-4/GAO Draft Report)

Now pp. 2-3.

DOD POSITION: Partially Concur. As part of the C-17 initial flap development effort, five specific tests were conducted to assess the flap durability and fatigue characteristics, as well as the operational environment. Three of the tests specifically focused on acoustic and temperature levels and intensities. Since the fact finding for this report was completed, significant test data and analysis information has become available.

In July 1986, during the boiler plate test, initial acoustic and temperature tests were accomplished by Douglas Aircraft Company. The test provided the initial criteria (150 degrees and 166 decibels) used for the original flap design and the basis for the follow on acoustic fatigue component test. The LTV Corporation conducted the acoustic fatigue component test during June-September 1990, using a representative section of the flap. Acoustic levels identified in the boiler plate test were used as a baseline during the test. Three problem areas were identified: (1) the structural attachment of the wing skin to the ribs lacked sufficient stiffness, (2) failure of several fasteners in the main box, and (3) the development of generalized skin panel cracking on the trailing edge. As a result of the identified problems, modifications were made to the flap section. Based on the accelerated test results, the original flap design was assessed to have a 400-hour life. The analysis resulted in the development of an improved production flap design.

The third test, conducted in February 1991 (flap impingement test), was designed to measure the operating environment on the flap. More representative of the actual aircraft configuration, the test collected acoustic, thermal, vibration, and strain data over a wide range of engine operating conditions and various flap positions. During the test, higher than expected temperatures (300 degrees) were measured in a small area of the flap directly behind the engine, and significantly lower than anticipated structural response was recorded reference the acoustic environment. Specific reasons for those differences were

identified and assessed. Exact replication of a complete flap with the required surrounding structures and attachments in a realistic operating environment is very difficult. The data collected in the February 1991 flap impingement test was the most representative available and was the first indication that the acoustic fatigue tests results from the 1990 LTV test were suspect. While the peak acoustic levels were verified in that testing, the structural response on the flap was completely different than that experienced on the component test. Further, investigation of the LTV component failure uncovered an error in the preliminary acoustic fatigue life analysis of the flap. The material database used in the original analysis was incorrect. Actual ground and flight test data collected to date on T-1 verifies the earlier jet impingement test results and invalidates the results of the component fatigue test. The flight test data also revealed that the temperatures experienced on the flap are a complex function of the flap setting, engine power setting, aircraft airspeed and altitude, and exposure time. The temperature limits on the original flap design are exceeded only at conditions involving full flap deflection, maximum engine thrust setting, and airspeeds less than 100 knots when sustained for more than one minute. Data collection is ongoing and additional evaluation of the design will take place, as necessary.

FINDING C: Air Force Review Team Recommendations Were Not Implemented. The GAO reported that the C-17 System Program Office requested an Air Force team to assess the life expectancy of the C-17 flap and determine if the Douglas Aircraft plan to achieve the contractual life requirement was sufficient. The GAO reported the review team determined that the initial structural design of the flap was unacceptable because the flap could not withstand the sound and temperature environment expected in service for the required life of the aircraft. The GAO observed that the review team also questioned the durability of the flap and concluded the flap program could and should be improved by doing the following:

- immediately starting a development test program, using representative test articles, to obtain design data to support the redesign analysis; and

- testing the final design of the flap through a combined heat and acoustic environment test to prove that the flap actually will achieve the 30,000 hours life expectancy requirement.

The GAO also observed that the team determined the problems with the flap developed because neither the Air Force nor Douglas Aircraft recognized the importance of the flap to the success of the C-17--and, therefore, its development did not receive sufficient management emphasis and resources.

The GAO found that Douglas Aircraft disputed the review team

findings, claiming the data gathered during the February 1991 temperature test (which took place after the review) showed that the flap would operate in a less stressful environment than prior tests had indicated. The GAO reported it was the view of Douglas Aircraft that the more recent test data would have changed the conclusions of the review team. The GAO showed the February test data to three of the four review team members, however, and they maintained the additional data would not have changed their conclusions and recommendations.

Finally, the GAO found that the Air Force and Douglas Aircraft have begun to acquire actual acoustic and temperature environment data from the flight test program, using the developmental aircraft. The GAO observed that, although the data will result in assessments of aircraft performance, it will not yield flap life-expectancy estimates. The GAO reported that life-expectancy estimates could only occur if the acquired data were used in an environment test--which would take into account the combined sound and heat effect on the flap. The GAO found, however, that Douglas Aircraft does not consider additional testing to be necessary and, instead, plans to rely on analysis and extrapolation from the data--the same methodology it used as the basis for the initial design of the flap. (p. 2, pp. 4-6/GAO Draft Report)

Now pp. 2-4.

DOD RESPONSE: Partially Concur. The C-17 System Program Office must consider all available information when reviewing recommendations. The independent review of the acoustic fatigue issue on the C-17 flap was initiated at the request of the C-17 program office. The independent review team report contained nine specific recommendations that provided the technical insight required to assess the problem areas and implement the necessary changes. When the February 1991 test data was presented to three of the four review team members after their report had been submitted, there was no in-depth explanation of the test methodology or detailed description of the results by the test manager or a technical expert. The program office had that additional information when the decision was made to go with a redesigned flap and address the test requirements. It is the responsibility of the C-17 program office to implement a solution with a high probability of success, in a timeframe consistent with program requirements, that is affordable in terms of program resources and within the context of all the other programmatic constraints. The nine recommendations made by the review team, were per their charter as an independent and impartial group. All the recommendations were reviewed and considered as important elements in the flap redesign decision making process, along with the February 1991 test data and actual inflight test data from the T-1 aircraft.

* * * * *

Now p. 4.

RECOMMENDATION

RECOMMENDATION 1: The GAO recommended that the Secretary of the Air Force direct the Program Executive Officer to establish test plans to determine whether the C-17 flap meets the 30,000 hour life expectancy performance contract requirement before the C-17 program goes into full-rate production. (p. 6/GAO Draft Report)

DOD POSITION: Partially concur. The recommendation is, however, moot. The C-17 test program already contains plans to determine the life expectancy of the flap to two lifetimes (60,000 hours) instead of only one lifetime as the GAO suggests. Developmental test and evaluation and initial operational test and evaluation must be completed prior to the Milestone III/B Defense Acquisition Board approval to proceed with full rate production. Therefore, further direction to the Program Executive Officer is unnecessary.

Testing on the flap has continued since the onsite work for the GAO report was concluded in September of 1991, including the completion of a major effort to obtain environmental and structural data on the T-1 flaps during flight test. The Air Force is planning to conduct a two lifetime (60,000 hour) durability test on the production design flap. The durability testing currently is scheduled to begin in November 1992, and be completed by October 1993. This is a cyclic load test to verify the life of the flap under the expected functional, aerodynamic, and maneuver loads. All production aircraft will have the improved flap design. Currently, the program office plans to conduct the static strength qualification tests for the flap with one of the original design flaps that was initially intended for P-1. The production flap will be stronger than the static test flap because of the additional improvements for acoustic fatigue.

The fully instrumented P-1 aircraft will be delivered to the C-17 flight test program at Edwards Air Force Base, California. As part of the flight test program, the flap will be specifically monitored and assessed in its full up production configuration on the aircraft and in the actual operational environment, to include acoustic and temperature related stresses. There is no more realistic test that can be accomplished on the flap than that which it will receive on the P-1 aircraft during the flight test program.

Major Contributors to This Report

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